Patent Claims

1. A photon-counting imaging device (50) for single x-ray counting comprising:

a) a layer of photosensitive material (4);

b) a source of bias potential (12);

c) a source of threshold voltage supply (U_T);

d) an NxM array of photodetector diodes (2) arranged in said layer of photosensitive material (4); each of said photodetector diodes (2) having a bias potential interface and a diode output interface (20), said bias potential interface of each photodetector diode (2) being connected to said bias potential (12);

e) an NxM array of high gain, low noise readout unit cells (18, 36), one readout unit cell (18, 36) for each photodetector diode (2);

f) each readout unit cell (18, 36) comprising an input interface (22) connected to said diode output interface (22), a high-gain voltage amplifying means (46) comprising a comparator unit (CA), a digital counter unit (48), comprising a digital counter (RSC), and a digital counter output interface (RBO) connected in series, each digital counter unit (48) counting an output signal of the comparator unit (CA); said output signal is proportional to a number of electron/hole pairs (10) generated by a photon (6) in the respective photodetector diode (2),

g) a multiplexing means (MM) comprising a row select (RS) and a column select (CS) circuit allowing to access each readout cell unit, i.e. to read out the digital data as actually stored in the digital counter (RSC) to the digital counter output interface;

h) each digital counter output interface (RBO) connected to an output bus

i) said output bus being connected to a data processing means (DPM) controlling the multiplexing means (MM).

2. The photon-counting imaging device (50) according to claim 1, characterized in that
the diode output interface (20) of the photodetector diodes (2) and the input interface (22) of the readout unit cell (18, 36) are connected to each other by bump bonding.

3. The photon-counting imaging device (50) according to claim 2, characterized in that
indium bumps (24) are used for the bump bonding.

4. The photon-counting imaging device (50) according to any one of the preceeding claims, characterized in that
the data processing means (DPM) are provided being connected via the multiplexer means (MM) to said array of readout unit cells (18, 36) allowing to control each of the readout unit cells (18, 36).

5. The photon-counting imaging device (50) according to claim 4, characterized in that
said data processing means (DPM) controls a enable/disenable switch (E/D) being comprised in said high gain voltage amplifying means (46), preferably in the comparator unit (CA).

6. The photon-counting imaging device (50) according to any one of the preceding claims, characterized in that
said source of threshold voltage supply (U_T) to said high-gain voltage amplifying means (46) comprises an adjustable source of threshold voltage correction supply (TC), both being controlled by the data processing means (DPM) via the multiplexer means (MM).

7. The photon-counting imaging device (50) according to any one of the preceding claims, characterized in that the data processing means (DPM) control via the multiplexing means (MM) one or more of the following issues:

a) programming of the readout unit cell via a port (DIN);
b) readout of the data in the readout unit cell via a port (DOUT);
c) calibration of the readout unit cell, preferably the high gain voltage amplifier means (46), via a port (CAL); and
d) analyzing the analog signal in the high gain voltage amplifier means (46) for the purpose of diagnosis via a port (AOUT).

8. The photon-counting imaging device (50) according to claim 1, characterized in that said NxM array of photodetector diodes (2), said NxM array of said readout unit cells (18, 36) being arranged on a first substantially flat support plate (52) for building a sensor module (54), and a sensor module control board (56) being arranged on a second substantially flat support plate (58); said first substantially flat support plate (52) and said second substantially flat support plate (58) being arranged under an angle (α) to each other.

9. The photon-counting imaging device (50) according to claim 8, characterized in that said angle (α) is in a range of 30 to 120°, preferably substantially 45 to 100°.

10. The photon-counting imaging device (50) according to claim 9 or 10, characterized in that a number of said sensor modules (54) being arranged in a substantially flat VxW array.

11. A photon-counting imaging device (26) for single x-ray counting comprising:

a) a layer of photosensitive material (4);
b) a source of bias potential (12);
c) a source of threshold voltage supply (U_T);
d) an NxM array of photodetector diodes (30) arranged in said layer of photosensitive material (4); each of said photodetector diodes (30) having a bias potential interface and a diode output interface (20), said bias potential interface of each photodetector diode (30) being connected to said bias potential (12);
e) an NxM array of high gain, low noise readout unit cells (36), one readout unit cell (36) for each photodetector diode (30) being controlled by a data processing means (DPM); and
f) the array of photodetector diodes (30) is designed as a microstrip detector (26) having N=1 columns and M>1, preferably $10 < M < 10^5$, rows.

12. A photon counting imaging device (26) according to claim 11, characterized in that
each readout unit cell (36) comprises an input interface (22) connected to said diode output interface (20), a high-gain voltage amplifying means (46) comprising a comparator unit (CA), a digital counter unit (48), comprising a digital counter (RSC), and a digital counter output interface (RB) connected in series, each digital counter unit (48) counting an output signal (OS) of the comparator unit (CA); said output signal (OS) is proportional to a number of electron hole pairs (10) generated by a photon (6) in the respective photodetector diode (30).

13. The photon-counting imaging device (26) according to claim 11 or 12, characterized in that
said rows having a width of about 5 to 50 µm, preferably about 10 to 20 µm, a length of about 0.5 to 50 mm, preferably 5 to 10 mm, and a of pitch of 10 to 100 µm, preferably 25 to 75 µm.

14. The photon-counting imaging device (26) according to any one of the preceding claims 11 to 13, characterized in that, said source of threshold voltage supply (U_T) to said high-gain voltage amplifying means (46) comprises an adjustable source of threshold voltage correction supply (TC), both being controlled by the data processing means (DPM).

15. The photon-counting imaging device (26) according to any one of the preceding claims 11 to 14, characterized in that the data processing means (DPM) provide means for enhancing the position resolution of an incident photon (6); said means for enhancing the position resolution comprising a comparator means comparing the signals of two adjacent photodetector diodes (30).

16. The photon-counting imaging device (26) according to claim 15, characterized in that
the data processing means (DPM) allow to determine an average amplitude (A_{max}) for the gain of the electron hole pairs (10) generated by an incident photon (6) and to set a threshold voltage (V_{Thresh}) corresponding to less than half of the average amplitude (A_{max}); said data processing means (DPM) evaluate coincident output signals (OS) in adjacent readout unit cells (36) in order to disenable the counting in the adjacent readout unit cells (36) having delivered the lower output signals (OS).

17. The photon counting imaging device (26) according to claim 15, characterized in that
the data processing means (DPM) allow to determine an average amplitude (A_{max}) for the gain of the electron hole pairs (10) generated by an incident x-ray photon and to set a threshold voltage (V_{Thresh}) corresponding to less than half of the average amplitude (A_{max}); the data processing means (DPM) generate a virtual intermediate photodetector diode between two adjacent photodetector diodes (30); and an incident photon (6) is assigned to said virtual intermediate

photodetector diode in case the output signals (OS) in two readout unit cells (36) assigned to adjacent photodetector diodes (30) exceed said threshold voltage (V_{Thresh}).

18. The photon-counting imaging device (26) according to any one of the preceding claims 11 to 17, characterized in that the data processing means (DPM) control one or more of the following issues:

a) programming of the readout unit cell (36) via a port (DIN);
b) readout of the data in the readout unit cell (36) via a port (DOUT);
c) calibration of the readout unit cell (36), preferably the high gain voltage amplifier means (46), via a port (CAL); and
d) analyzing the analog signal in the high gain voltage amplifier means (46) for the purpose of diagnosis via a port (AOUT).

19. A photon counting imaging device (14, 26, 50) for single x-ray counting comprising:

a) a layer of photosensitive material (4);
b) an NxM array of photodetector diodes (2, 30) arranged in said layer of said photosensitive material (4);
c) an NxM array of high gain, low noise readout unit cells (18, 36), one readout unit cell (18, 36) for each photodetector diode (2, 30); the readout unit cells (18, 36) being controlled by a data processing means (DPM);
d) each readout unit cell (18, 36) comprising an internal data processing means (ROI SEL) allowing to assign each output signal (OS) representing an incident photon (6) or a predetermined number of incident photons (6) in the corresponding photodetector diode (2, 30) to a preselectable region of interest (ROI); and
e) said assignment of the output signal is accompanied by a time stamp.

20. A photon counting imaging device (14, 26, 50) according to claim 19, characterized in that
each readout unit cell (18, 36) comprises an input interface (22) connected to said diode output interface (20), a high-gain voltage amplifying means (46) comprising a comparator unit (CA, COMP), a digital counter unit (48), comprising a digital counter (SRC), and a digital counter output interface (RB) connected in series, each digital counter unit (48) counting the output signal (OS) of the comparator unit (CA, COMP);
said output signal (OS) is additionally directed to a region of interest unit (ROI SEL); said region of interest unit (ROI SEL) being part of the readout unit cell (18, 36) or being part of the external data processing means (DPM).

21. The photon-counting imaging device (14, 26, 50) according to claim 19 or 20, characterized in that
at least one predeterminable region of interest (ROI) is comprised, whereby a preselectable number of elected photodetector diodes (2, 30) build this region of interest (ROI);
the output signal (OS) in each elected corresponding readout cell unit (18, 36) being processed to a region of interest unit (ROI SEL) causing the output interface ($ROI(0,\ldots,K)_{out}$), corresponding to the region of interest (ROI) hit by an incident photon (6) to set a region of interest hit signal; said region of interest hit signal is aligned by the time stamp originated by an external or an internal clock means.

22. The photon-counting imaging device (14, 26, 50) according to claim 21, characterized in that
the data processing means (DPM) provides a means for storing either the time stamp or an information comprising the time stamp and the corresponding regions of interest (ROI) which was hit by an incident photon (6) originally causing the output signal (OS).

23. The photon-counting imaging device (14, 26, 50) according to claim 21 or 22, characterized in that
the region of interest unit (ROI SEL) comprises a counter means for which a threshold for setting a region of interest hit signal is determinable.

24. The photon-counting imaging device (14, 26, 50) according to any one of the claims 21 to 23,
characterized in that
the external or the internal clock means are resetable and operates with a frequency in the range of 10 to 500 MHz, preferably about 100 MHz.

25. The photon-counting imaging device according to any one of the preceding claims 19 to 24,
characterized in that,
a number of at least two regions of interest (ROI) are provided, each of the at least two regions of interest (ROI) having a programmable time-related validity.